Advances in Wind Technology

Robi Robichaud

November 1, 2006

Overview:

- Wind resource – mapping and assessment
- Wind turbine installations, market, incentives - Europe, U.S. and the world
- Technology issues and progress
    - Blades
    - Drivetrains/Generators
    - Towers
    - On-shore vs. Off-shore
- Future cost trends

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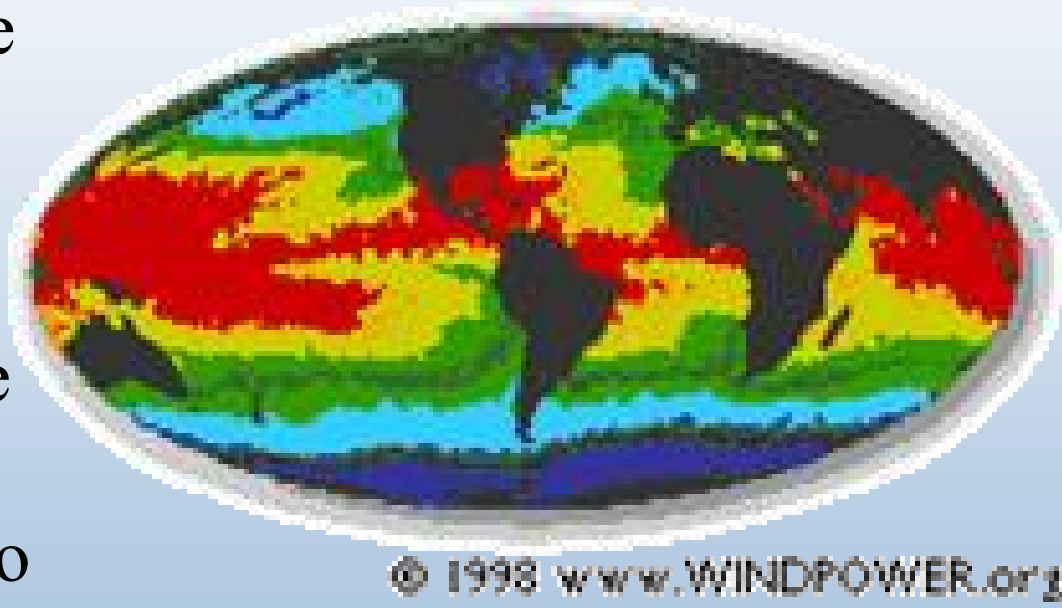
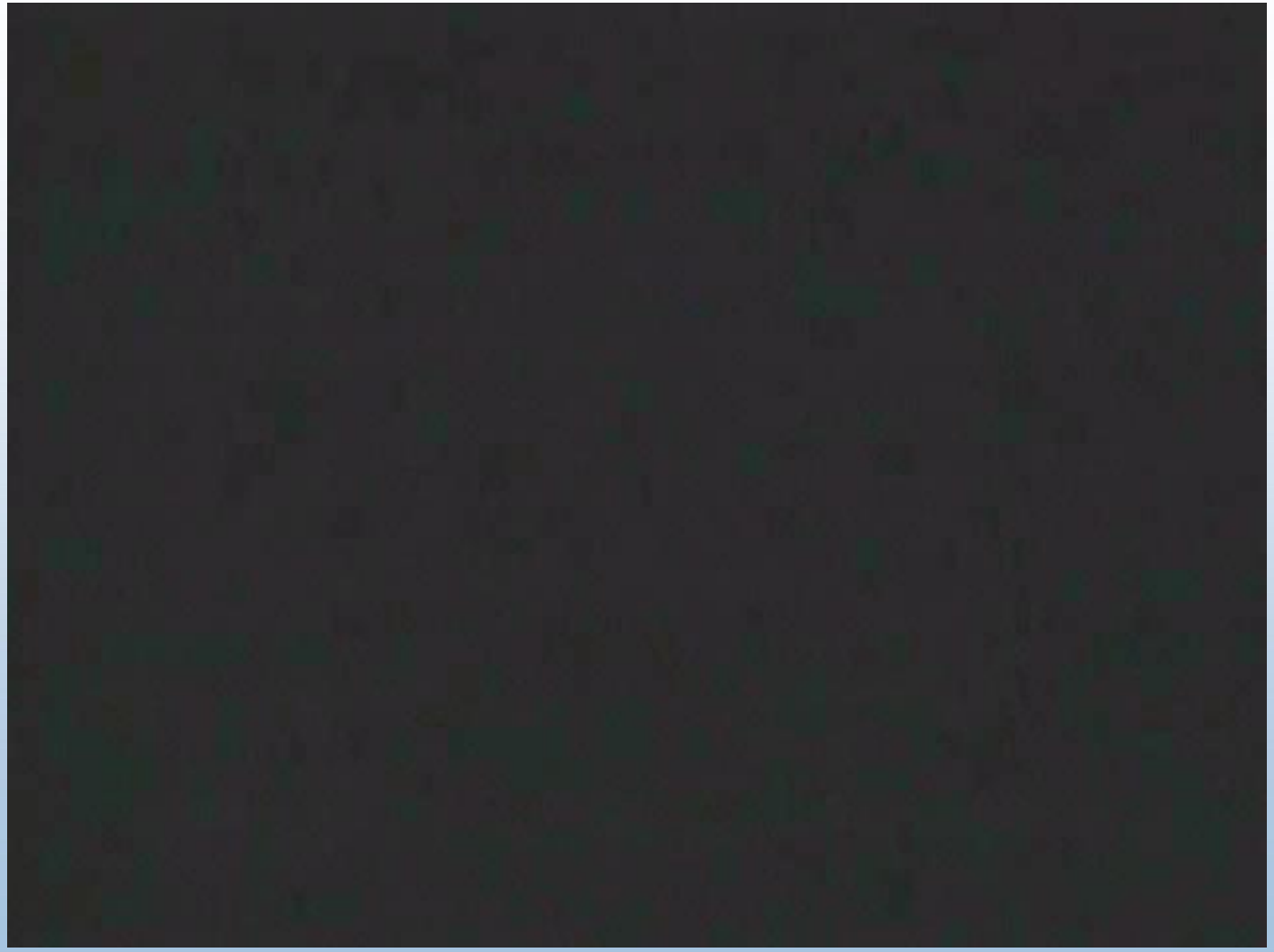
What is Wind Power?

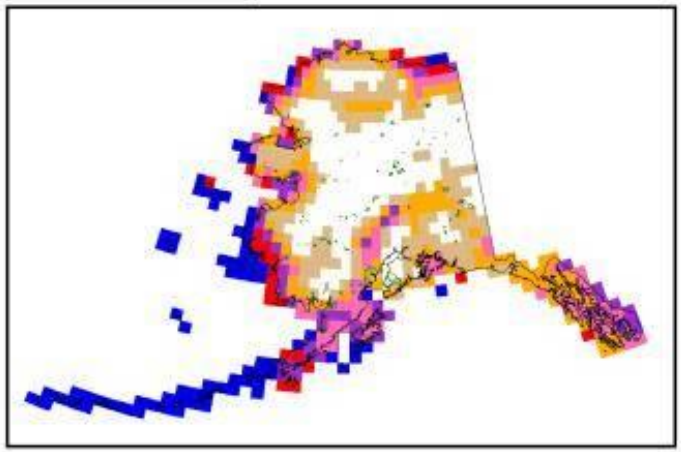
- Wind energy is created by uneven solar heating of the earth
- Use of wind power dates to ancient civilizations
- Principles similar to those involved in sailing - tranforming wind energy to mechanical energy
- One step beyond – mechanical to electrical



Why Use Wind Power?



United States - Wind Resource Map



Source: "Wind Energy Resource Atlas of the United States", 1987

Indian Reservations and Alaska Native Village Areas

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

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NREL

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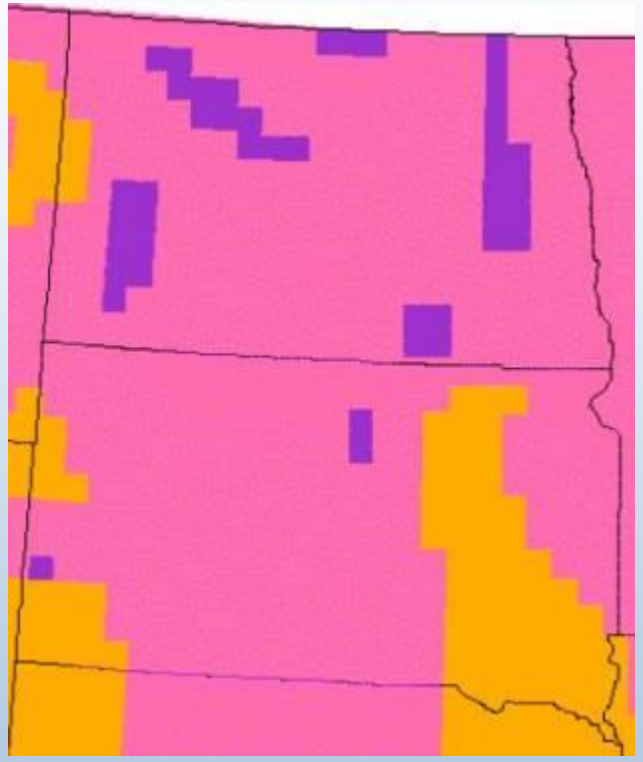
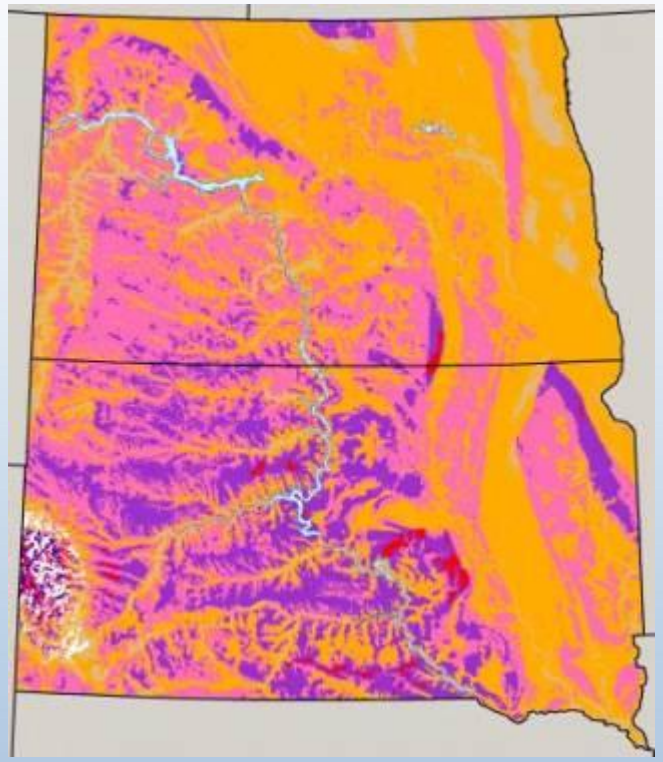
Growing to Support the Needs of Industry

Wind Resource Maps for North and South Dakota



1987



2000

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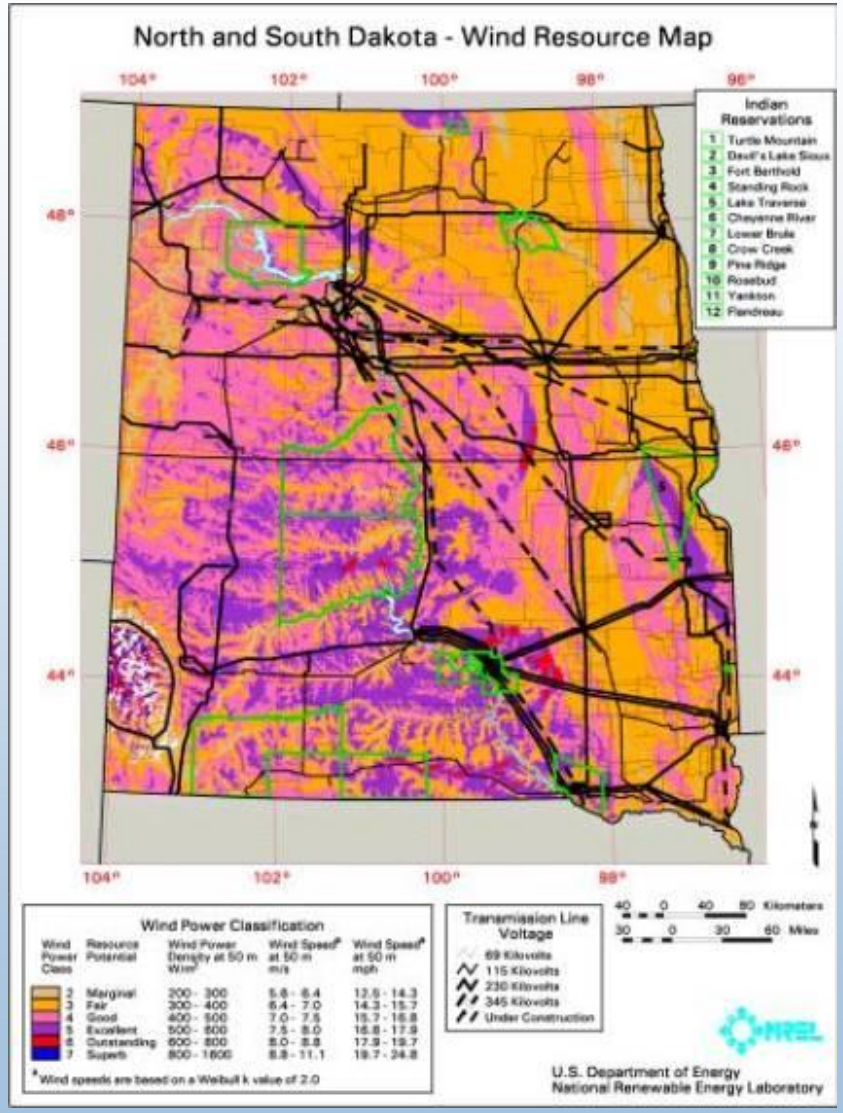
[a] Wind speeds are based on a Weibull k value of 2.0

Wind Resource Mapping

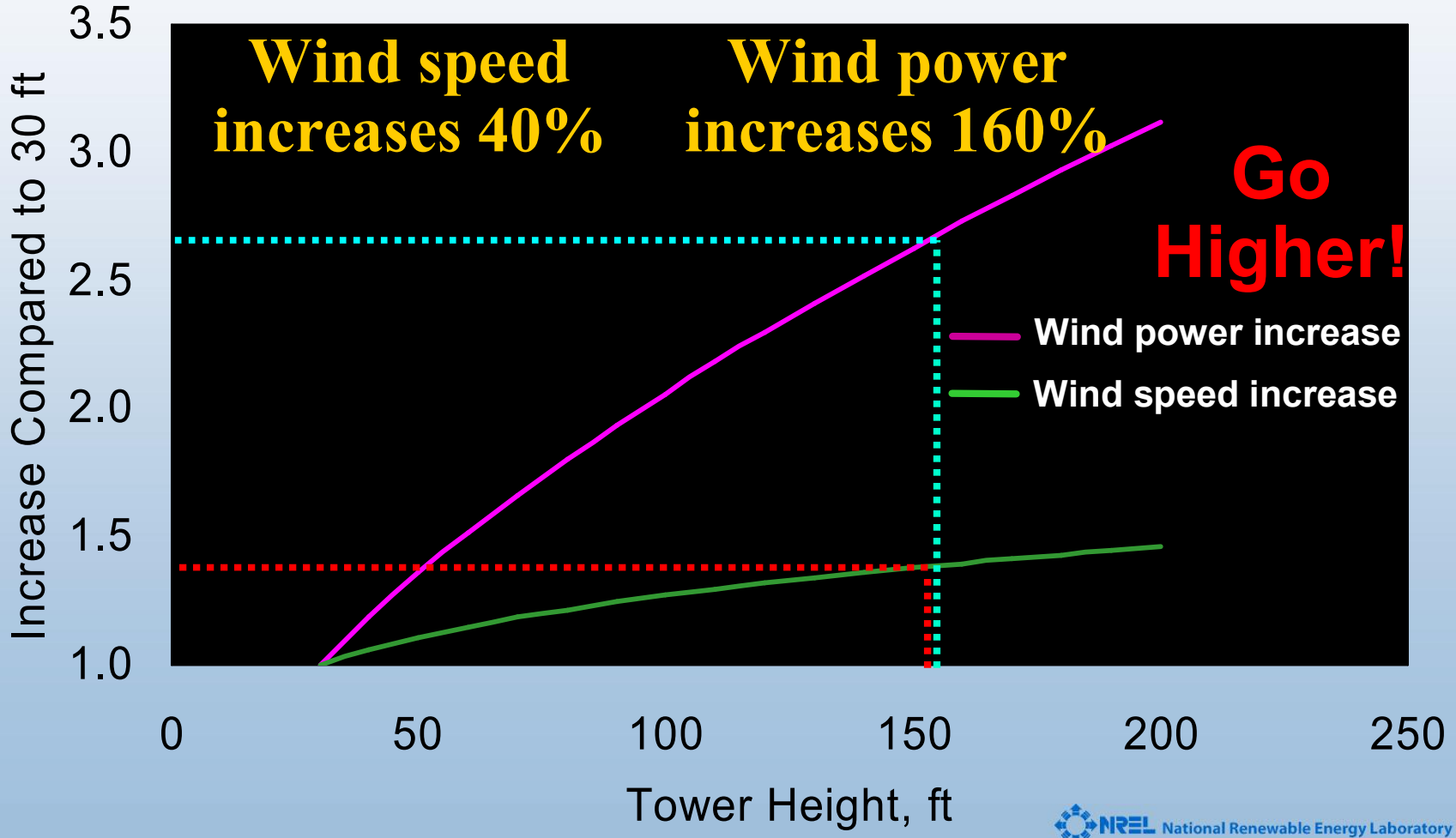
- Identifies most promising areas for wind energy development
- Employs geographic information system technology to create layers of key information
- Used by state energy planners, Indian tribes, and developers
- Approach changing from empirical to numerical modeling techniques
- Forecasting, resource assessment and site specific inflow quantification methods are likely to converge into a single approach



Energy in the Wind

- Wind energy is kinetic energy--mass and momentum.
  $P = A \times \rho V^3/2$
  - P = power of the wind [Watts]
  - A = windswept area of the rotor (blades) = $\pi D/4 = \pi r^2$ [m^2]
  - ρ = density of the air [kg/m^3] (at sea level at 15°C)
  - V = velocity of the wind [m/s]
- **Wind energy is proportional to velocity cubed (V^3):**
  - **If velocity is doubled, power increases by a factor of eight ($2^3 = 8$) !**
  - Small differences in average speed cause big differences in energy production.

Wind Speed and Power Increase with Height Above the Ground



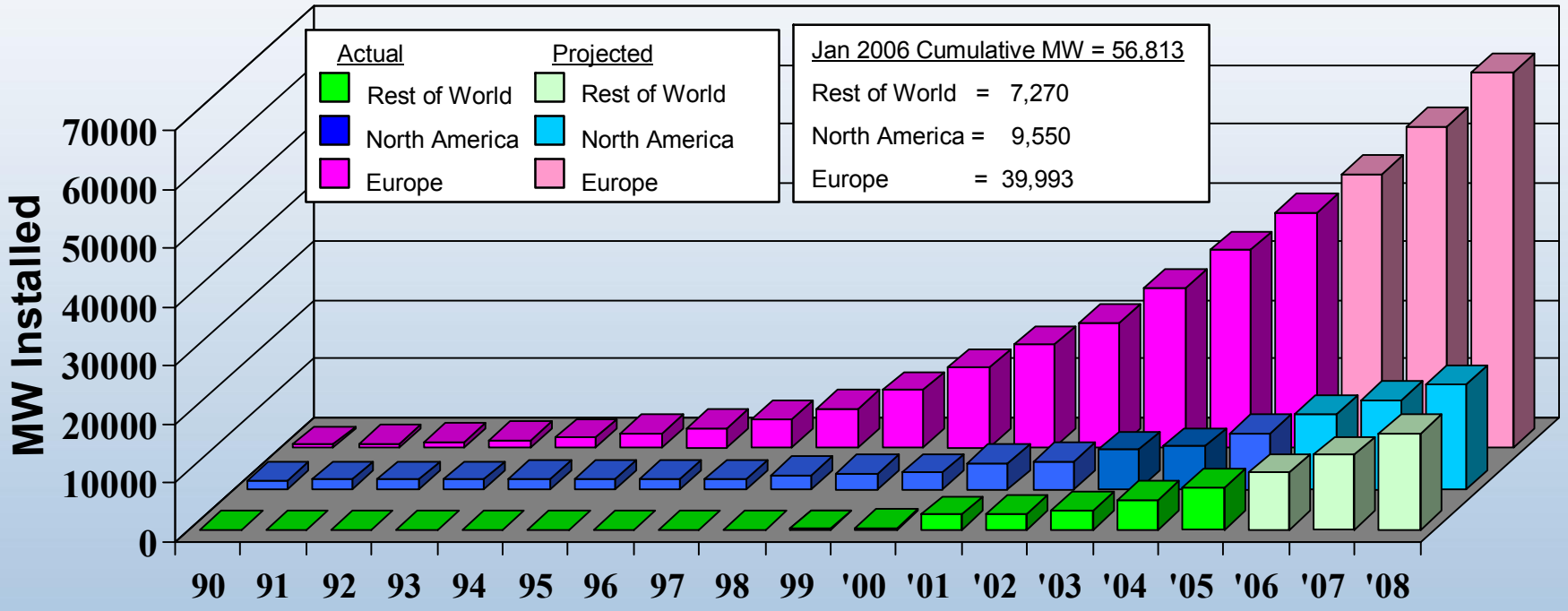
Relative Size of Swept Area (Small Turbine)

$A = Pi\ D^2 / 4$

Credit: Paul Gipe

Go Bigger !

Growth of Wind Energy Capacity Worldwide



Sources: BTM Consult Aps, Sept 2005
Windpower Monthly, January 2006

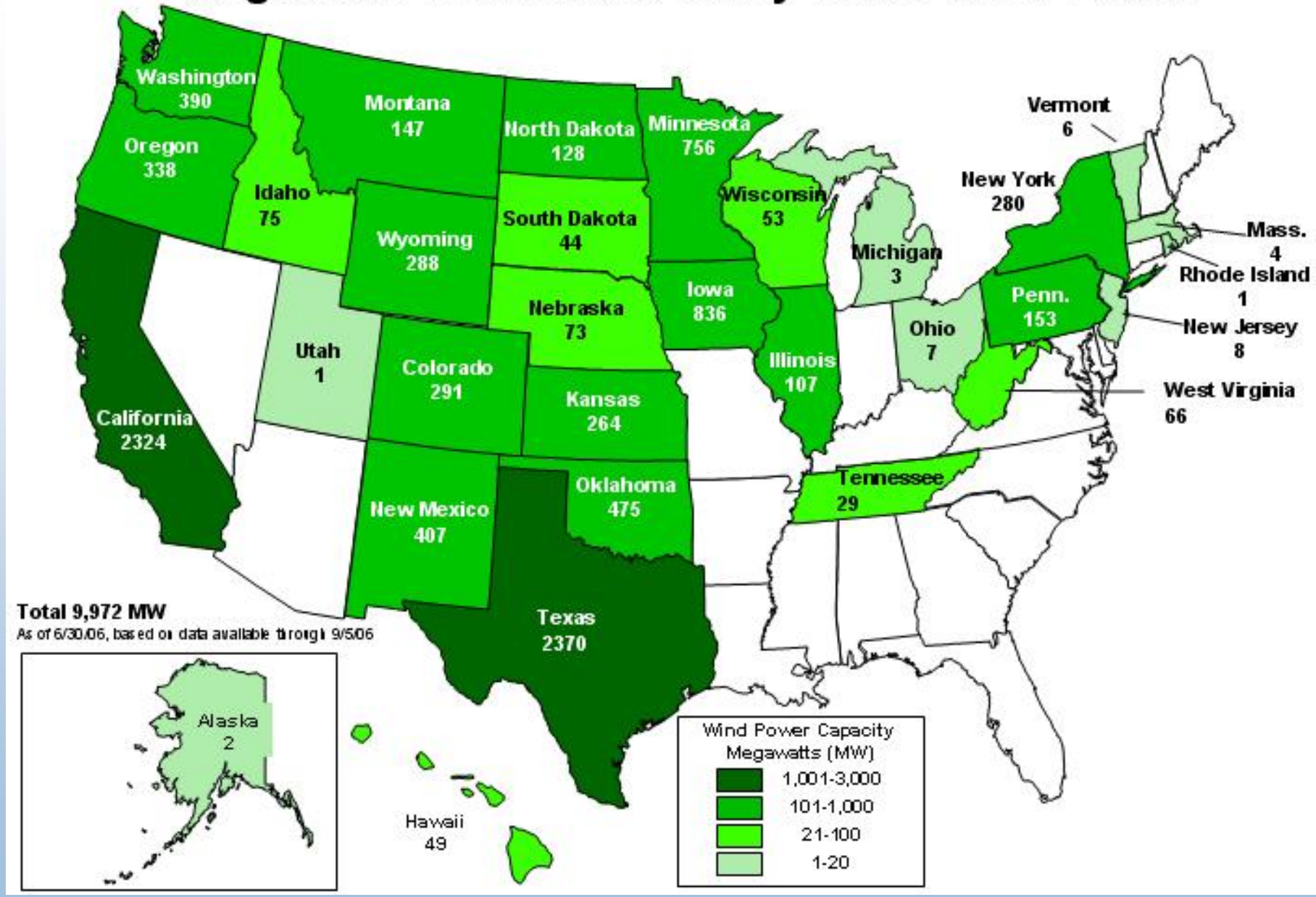
International Market Drivers

- Europe
  - high mandated purchase rates (85-90% of retail, 10-12 cents/kWh)
  - strong government and public commitment to the environment, including climate change
  - population density & existing developments driving off shore deployment in Europe
- Developing World
  - huge capacity needs
  - lack of existing infrastructure (grid)
  - pressure for sustainable development (climate change)
  - tied aid

Finances and Incentives

- Production Tax Credit
  - 1.9 cents/kWh (escalating) for 10 years equates to around 1.1 cents/kWh reduction in contract price
  - deadline pressure *increases* costs
- State and Local tax, etc. can be significant
  - +/- 0.5 cents/kWh impact
- Renewable Energy Production Incentive
  - annual appropriations problem leads to little impact
- Renewable Portfolio Standards
  - require x% of energy from renewables – can be a driver of utility power source decisions
- EPAct 2005
  - requires federal agencies to use increasing % of RE – 3.0% in 2007 to 7.5% in 2013

Megawatts of Installed Utility-Scale Wind Power



Sizes and Applications

Small (≤10 kW)

- Homes (Grid connected)
- Farms
- Remote Applications

(e.g. battery changing, water pumping, telecom sites, icemaking)

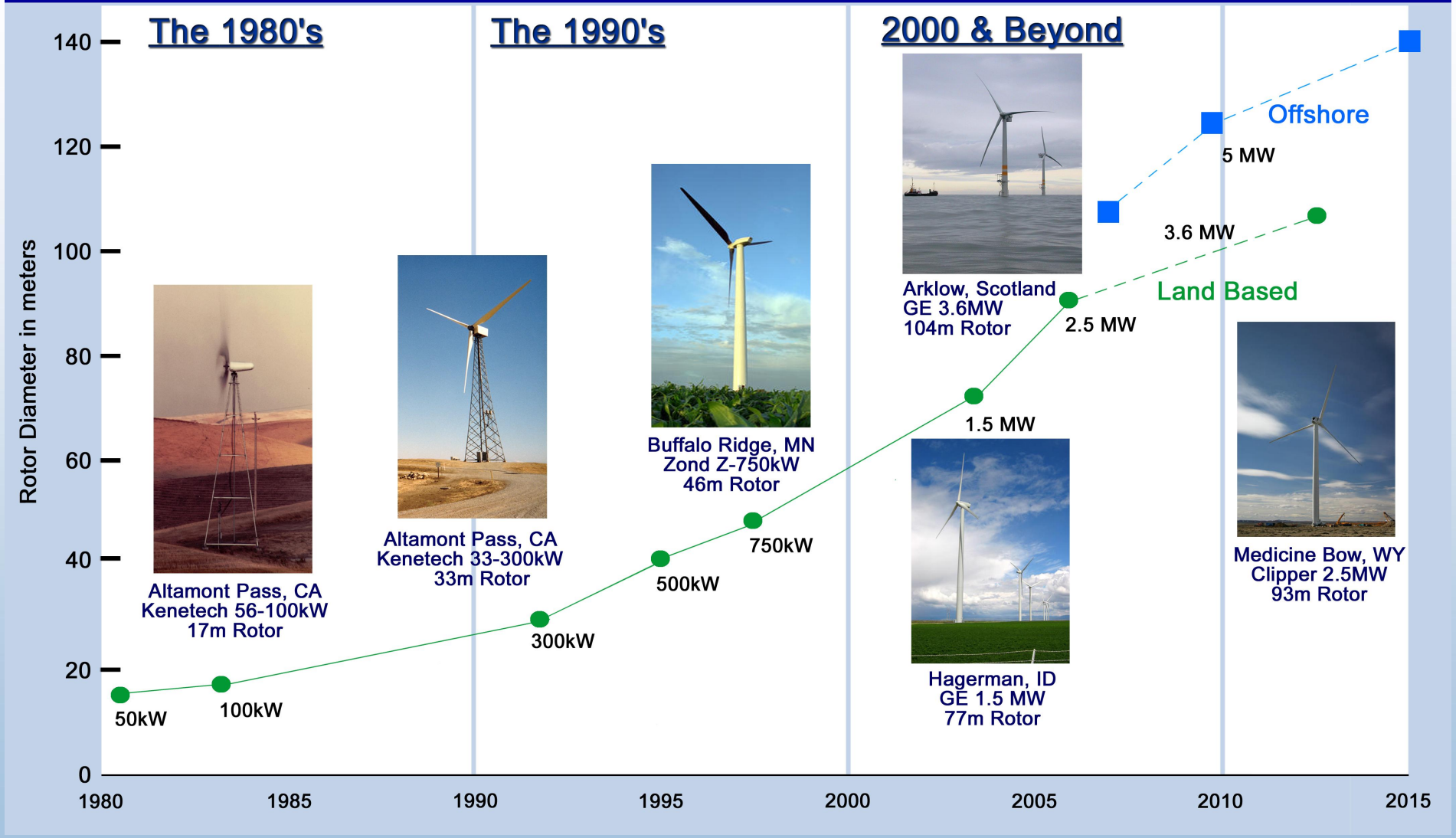
Intermediate (10-500 kW)

- Village Power
- Hybrid Systems
- Distributed Power

Large (500 kW – 6 MW)

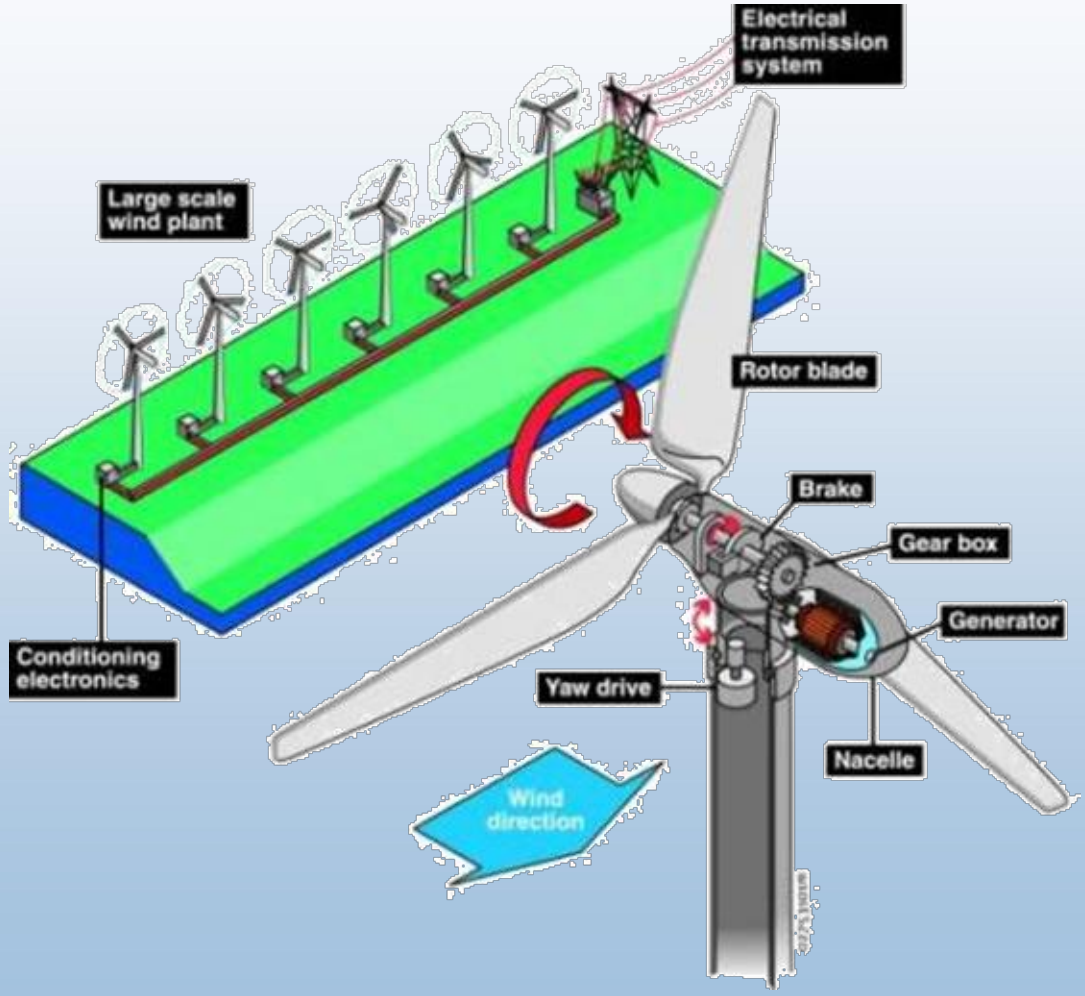
- Central Station Wind Farms
- Distributed Power
- Offshore Wind Generation Stations

Evolution of U.S. Commercial Wind Technology



Wind Energy Technology

At it's simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity. Large turbines can be grouped together to form a wind power plant, which feeds power to the electrical transmission system.



Cost of Energy Trend

1981: 40 cents/kWh

Decreasing Cost Due to:

- **Increased Turbine Size**
- **R&D Advances**
- **Manufacturing improvements**

NSP 107 MW Lake Benton, MN wind farm

2006: 5-8 cents/kWh with no PTC

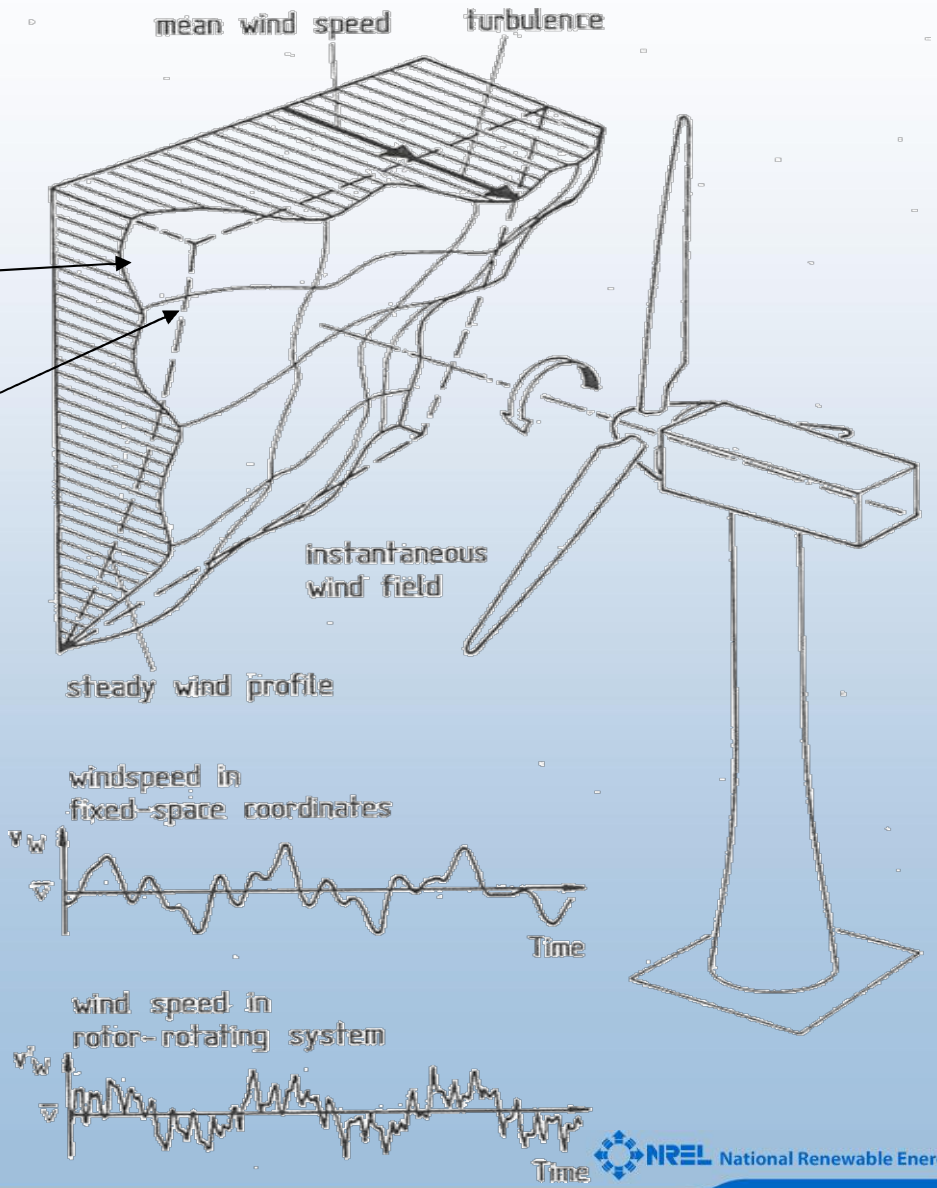
Cost Increases Due to:

- **Price increases in Steel & Copper**
- **Turbines Sold Out for 2 Years**

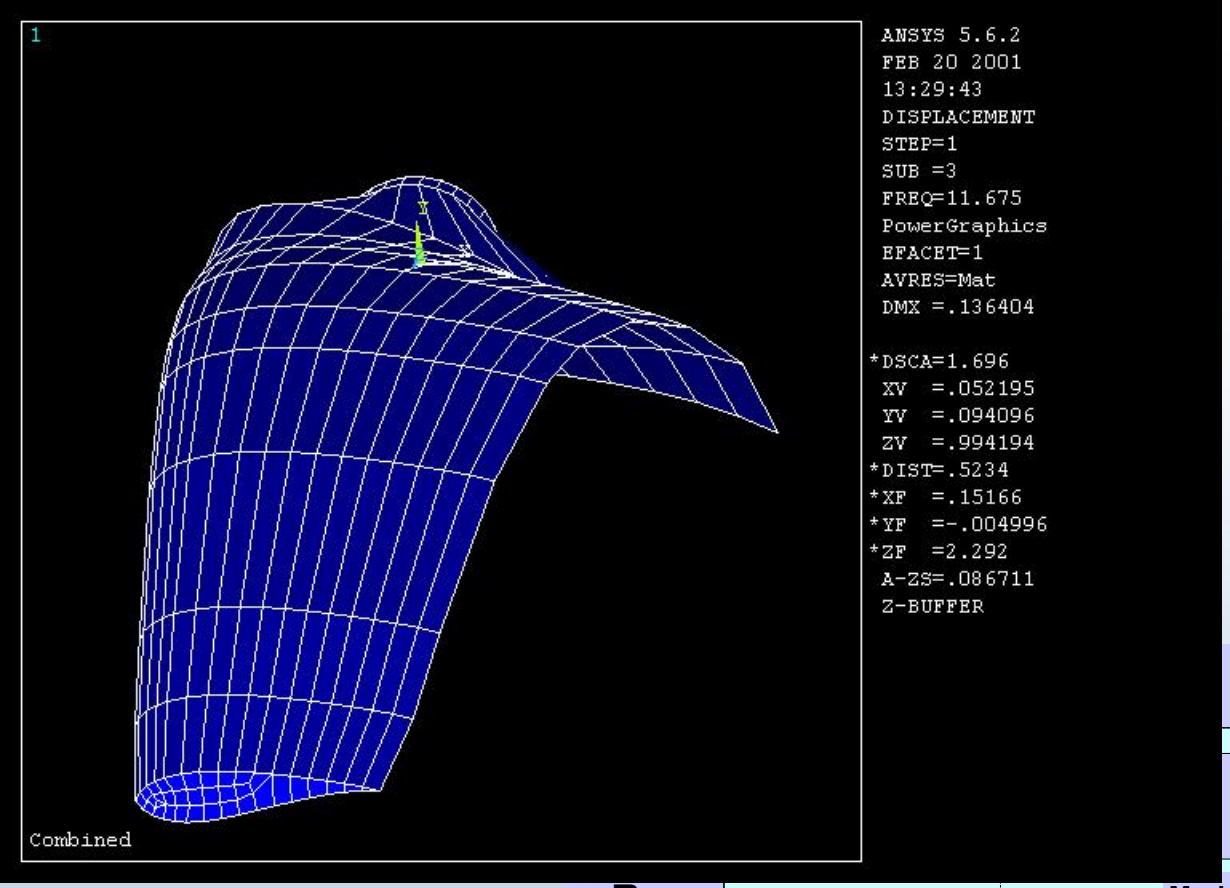
2012 Goal : 3.6 cents/kWh with no PTC

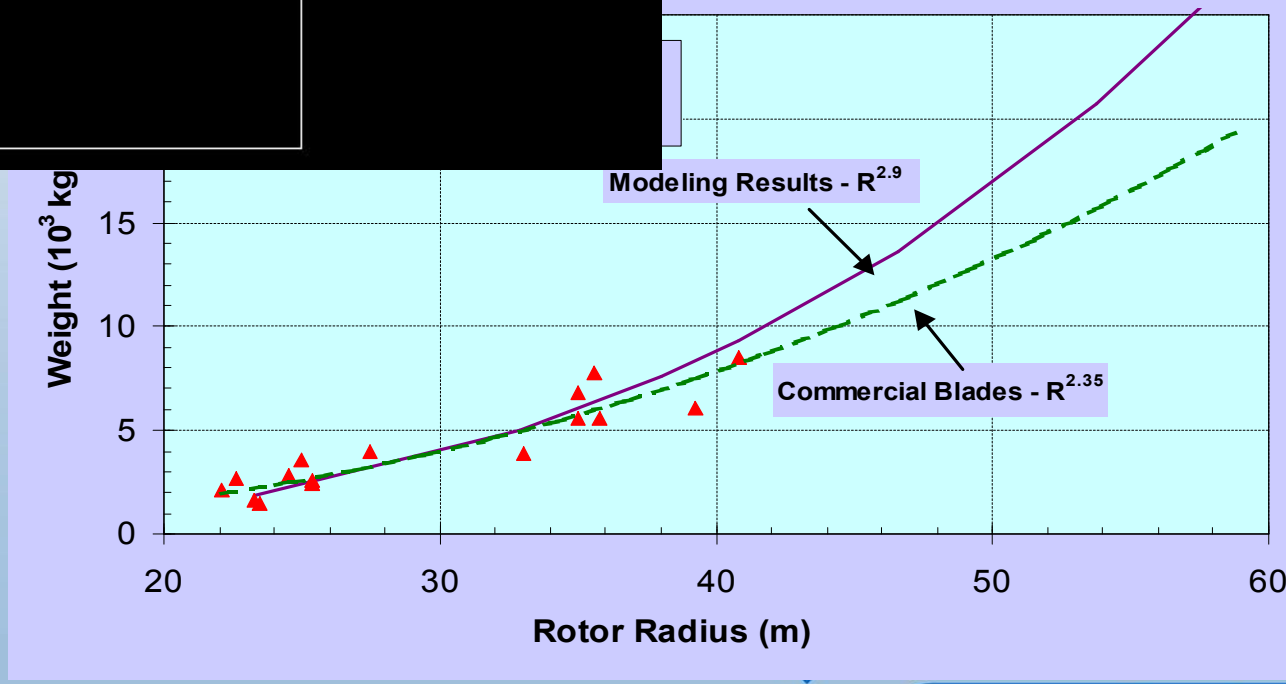
Dynamic Loading Environment

- **Wind field = U (y,z,t)**
- **Steady wind shear superimposed**
- **Rotational sampling effect increases effective wind fluctuations**



Blade Scaling for Multi-megawatt Rotors

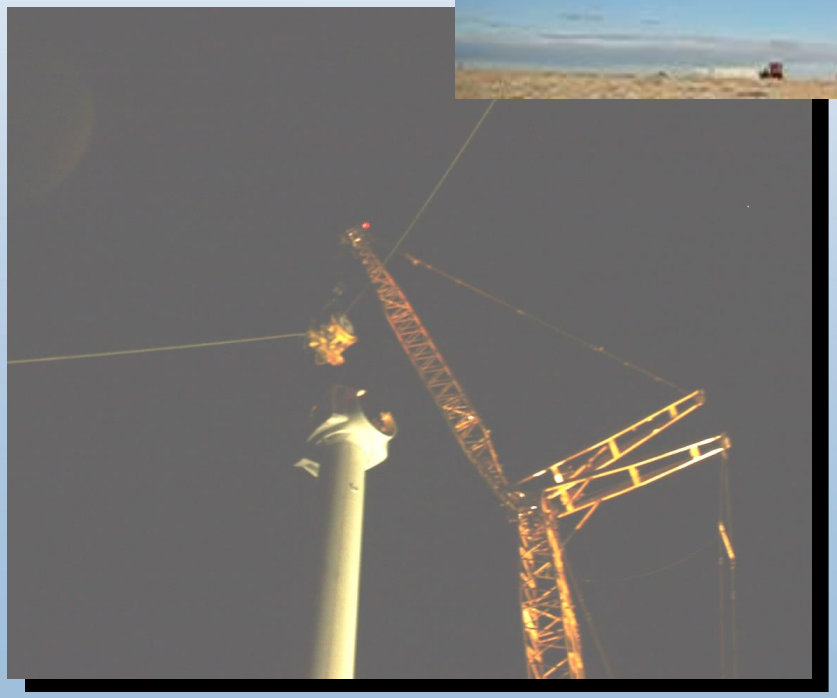




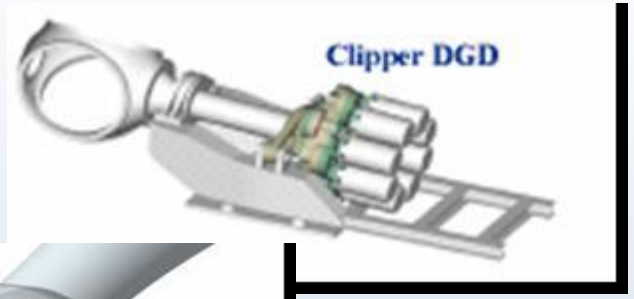
Industry's Growing Needs

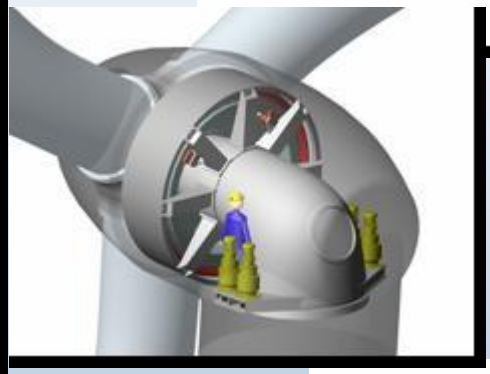
A new 45-meter wind turbine blade was shipped to the NWTC for testing in July 2004.

Clipper LWST Prototype
2.5 MW with 93 m Rotor

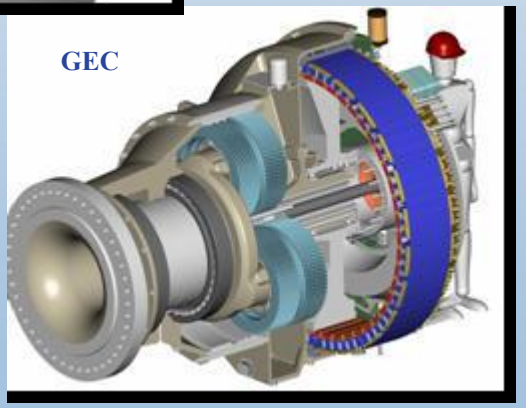


Advanced Drivetrain R&D





Tomorrow



Tall Towers

Tall Tower Concepts:

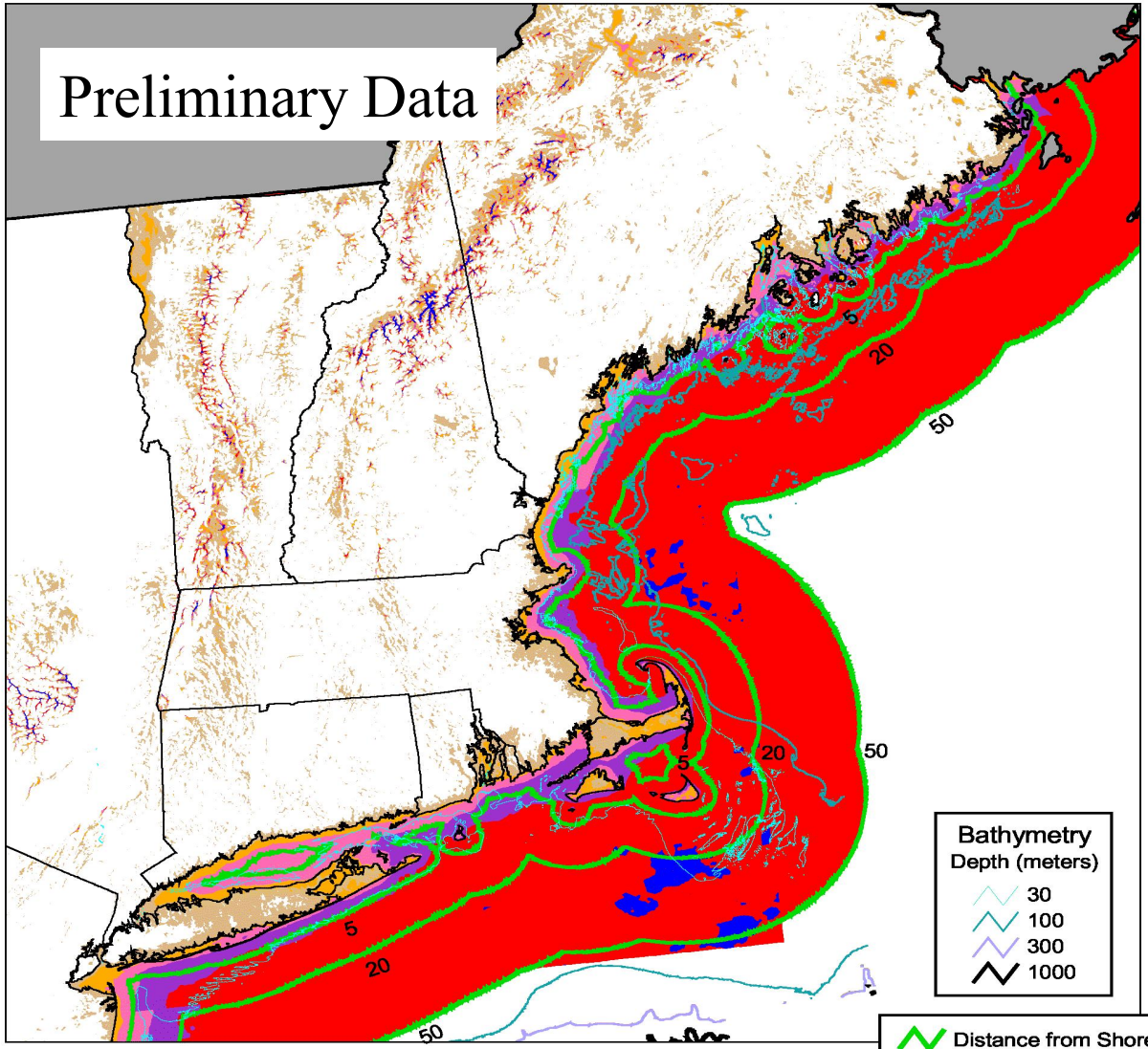
- Novel Steel tubes
- Truss towers
- Pre-stressed concrete
- Composite
- Hybrid towers
- Self-erecting/no cranes
- On-site manufacturing
- Tower load feedback control

Self Erection Concepts

Telescoping Tower

Jack Up Tower

Offshore Wind Potential for New England



New England Offshore Wind Resource Potential

All areas > 5 nautical miles offshore likely to be class 4 resource or better.

Area 5-20 nautical miles from shore (67% excluded):
- 10,300 sq. km. (51,500 MW)
- 1,980 sq km (9,900 MW) <30m depth

Area 20-50 nautical miles from shore (33% excluded):
- 33,800 sq. km. (169,000 MW)
- 540 sq km (2,700 MW) <30m depth

The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data, and has been validated by NREL.

The bathymetry contour lines were derived from NOAA's coastal relief models (nominal resolution 1 km) from NOAA's National Geo-physical Data Center.

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[a] Wind speeds are based on a Weibull k value of 2.0

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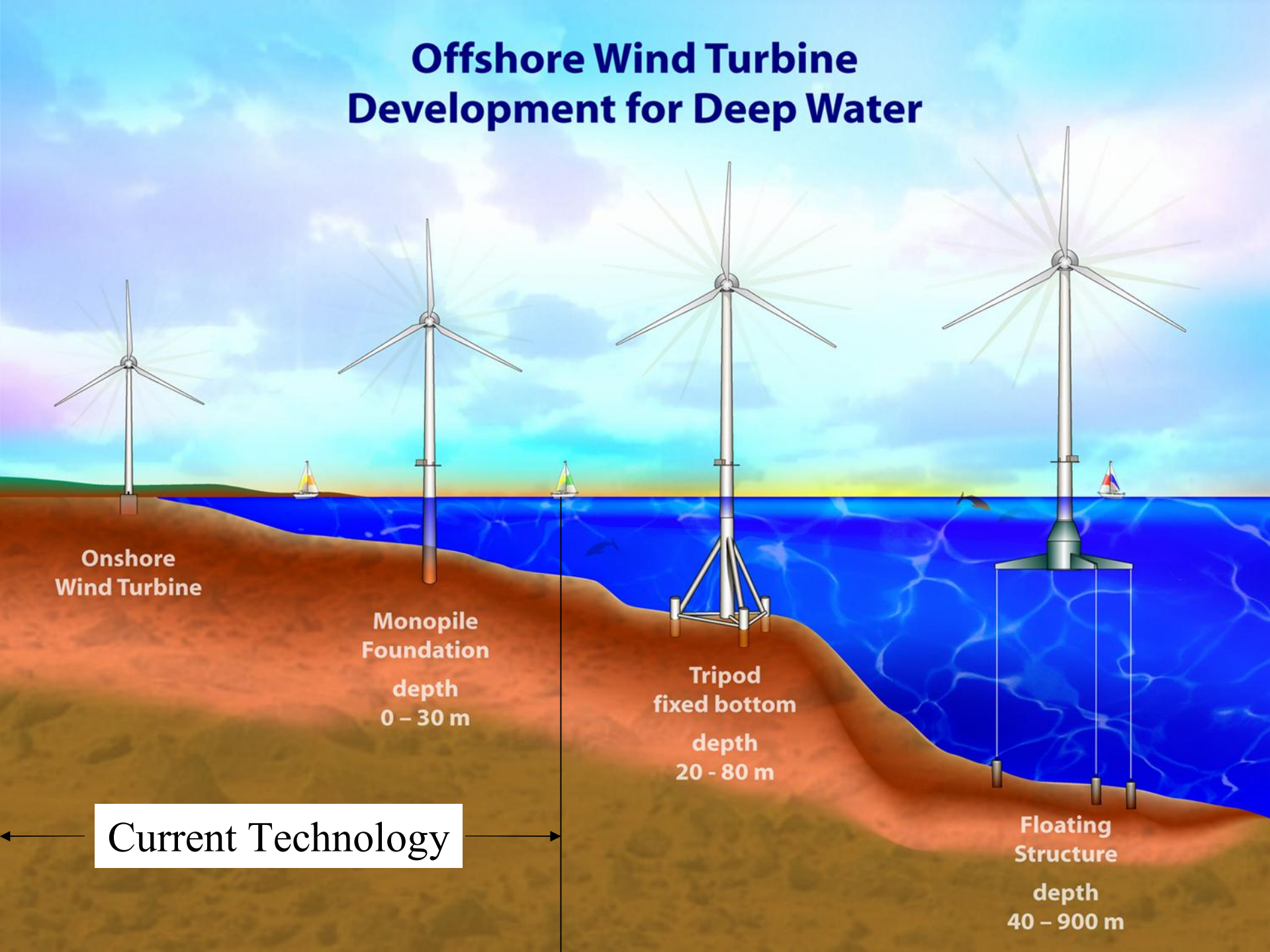
30-JUL-2003 2.1.2


Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology

Arklow Banks Windfarm
The Irish Sea

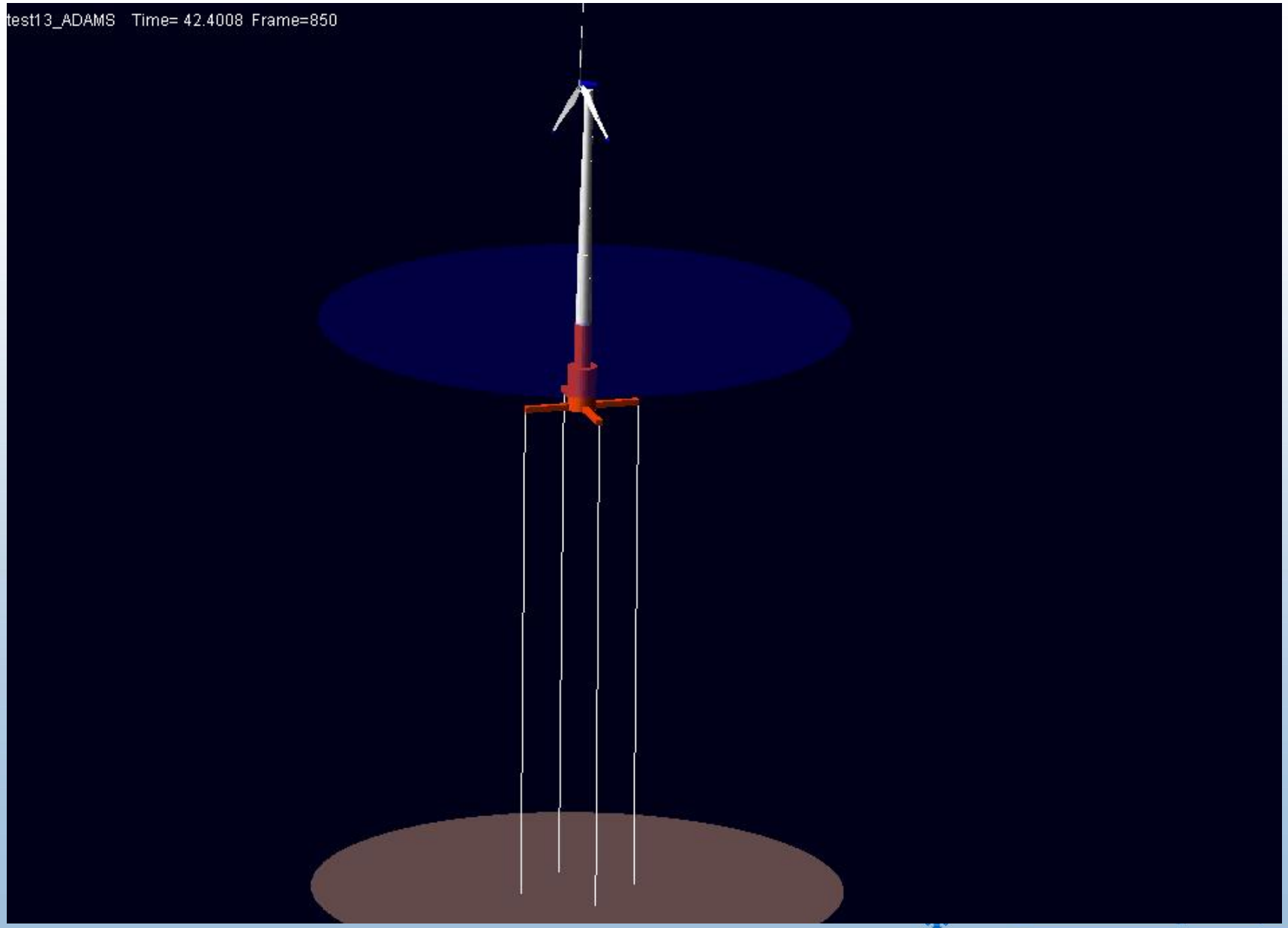
Photo: R. Thresher

Enercon
Offshore Prototype

Enercon 4.5MW 112 meter rotor

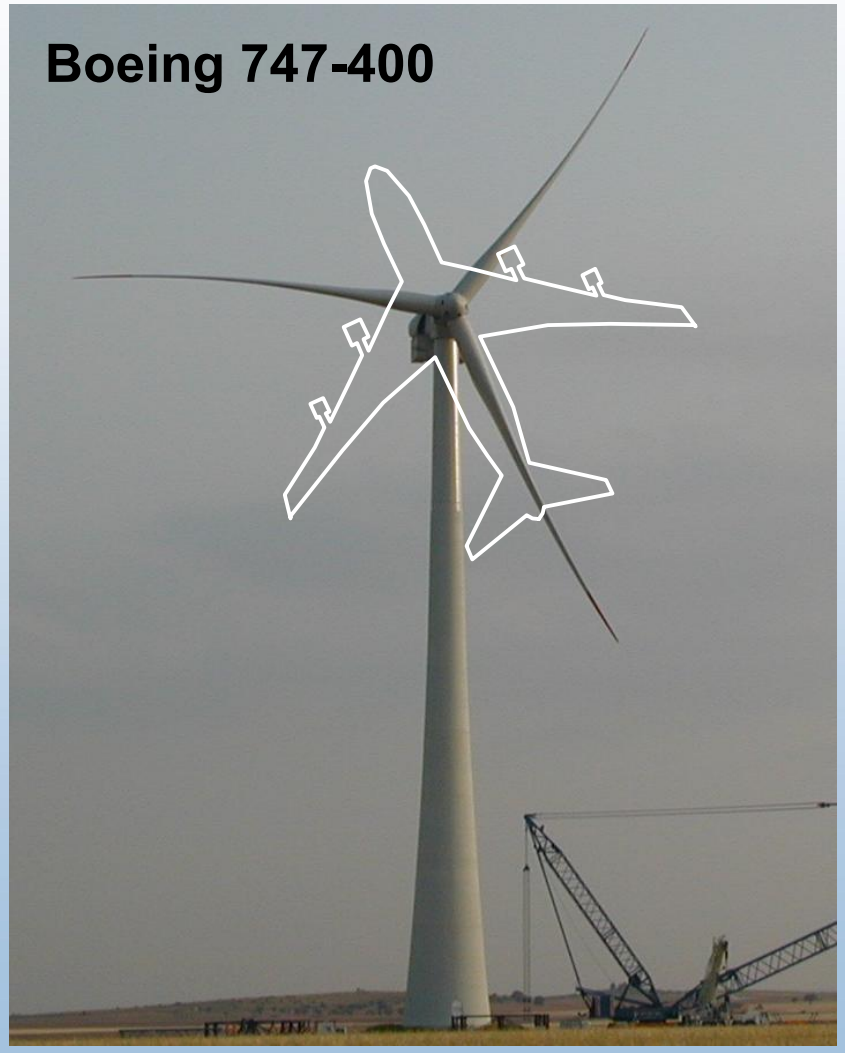
440 metric tonnes

MIT ADAMS Model



GE Wind Energy
3.6 MW Prototype

- Design concept similar to offshore GE 1.5 / 70.5
- Offshore GE 3.6 MW
  104 meter rotor diameter
- Offshore design requirements considered from the outset:
  - Crane system for all components
  - Simplified installation
  - Helicopter platform



Wildlife-Related Research

- **Data suggest the most significant avian wind-turbine interaction problem in the U.S. is in the Altamont WRA.**
- **Generally speaking, avian issues can be managed at future wind farm developments by careful site selection.**
- **Two guidance documents have been adopted by the NWCC: (1) *Permitting of Wind Energy Facilities,* and (2) *Metrics and Methods for Avian Studies.* These two documents serve as guidance for siting and development of new wind farms in the U.S.**
- **Some current NWCC Wildlife Workgroup activities include developing: (1) a companion document focused on Methods and Metrics for Studying the Impacts of Wind Power on Nocturnal Species; (2) a protocol for investigating displacement effects of wind facilities on grassland songbirds; and, (3) a toolbox of potential mitigation options.**

The Challenging DOE Program Goals

Low Wind Speed Technology

- Develop wind turbine technology (>100kW) capable of 3.6 cents/kWh in Class 4 (13.4 mph wind site) by 2012
  - **Increase area available for wind energy development by a factor of 20 or more**
  - **Accelerate achievement of the domestic renewable energy generations capacity goal**

Distributed Wind Systems

- Reduce the cost of energy from distributed wind systems to $.10-$.15/kWh at Class 3 wind sites (12 mph wind site) by 2007
  - **Increase distributed energy capacity in the United States**

Low Wind Speed Technology – Significance to U.S. Wind Industry

Current Status of Wind Technology:

- Wind Technology has matured over 25 Years
- Availability now reported at 98-99%
- Certification to international standards for new turbine designs helps avoid "major failures"
- Current designs produce electricity for 5-8 cents/kWh at Class 6 wind sites (15 mph or higher average wind)

Low Wind Speed Technology Innovations for the future:

- Larger-scale 2 to 5 MW, with rotors diameters to 120 meters
- Flexible, thin high-speed rotors
- Extendable rotor concepts
- Hybrid glass-carbon rotors
- Load feedback control systems
- Custom designed low-speed, permanent-magnet generators
- Self-erecting tall tower designs, 85 to 100 meters tall
- Offshore wind turbines
- Wind/hydrogen production

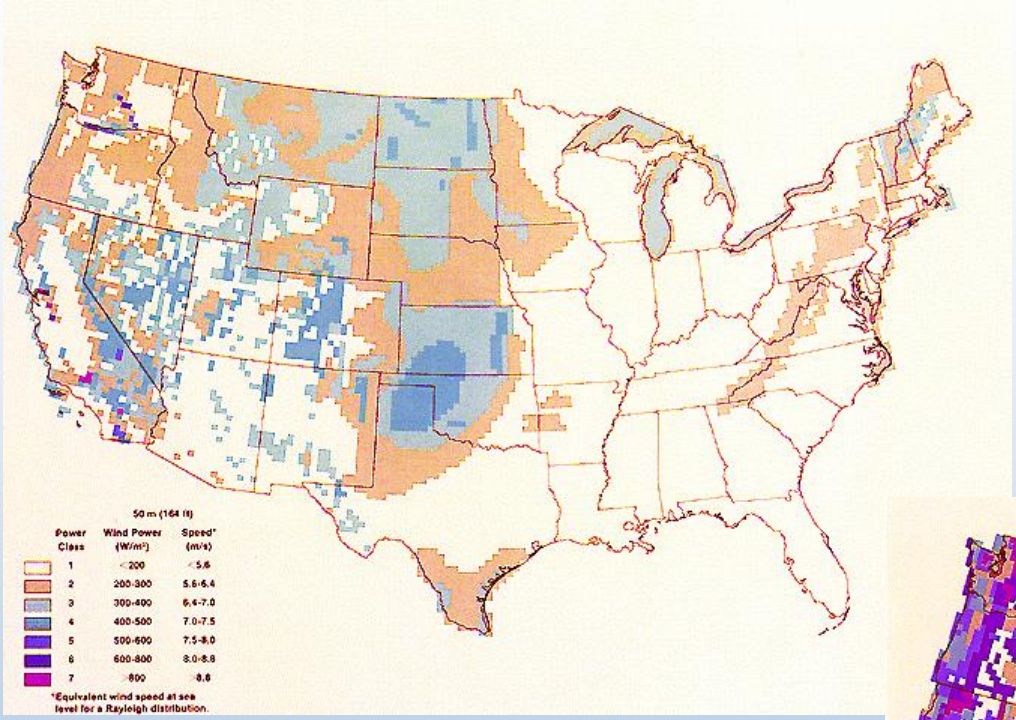
Small Wind Opportunities

Bergey BWC 10kW

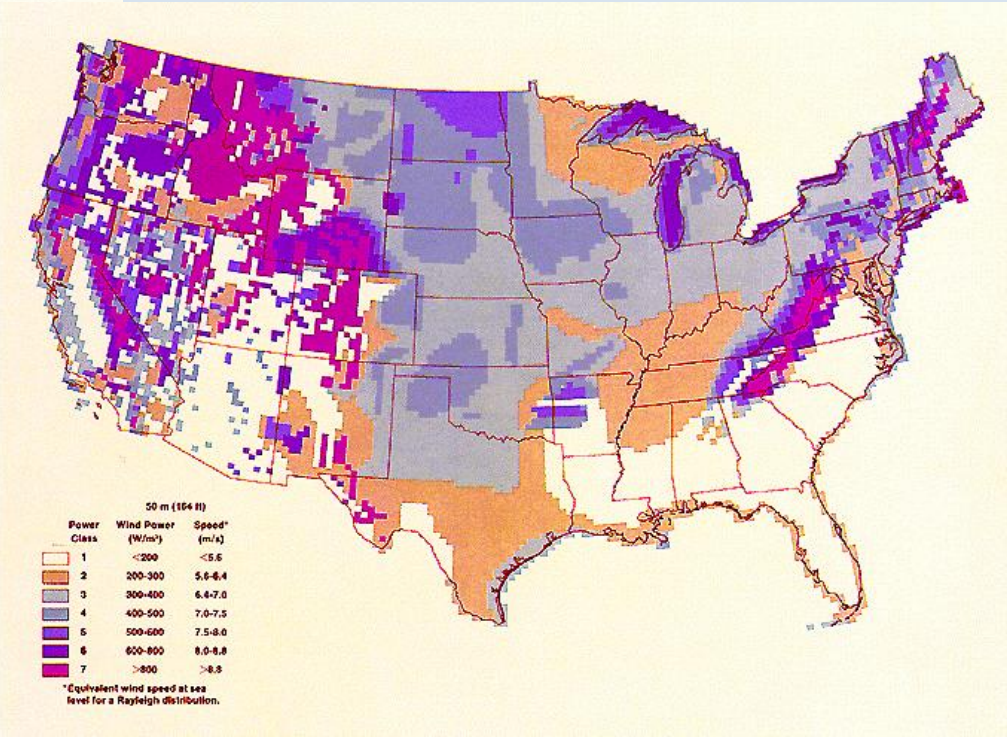
SWWP DWT Prototype 1.8kW under test at the NWTC

- Require average wind speeds above 4 m/s (9 mph)
- Cost-competitive when electric grid must be extended more than 1 km (0.6 miles) and annual consumption exceeds 300 kWh
- Generally competitive in applications with high energy costs, typically 12-70¢ /kWh.
  - Remote residences, water pumping
  - Telecommunications, navigation aids, etc.
- **Small turbines – can be used with PV/batteries in hybrid system** - take advantage of seasonal variations in wind and sun resource.

Wind Energy
US Summer Wind Resource



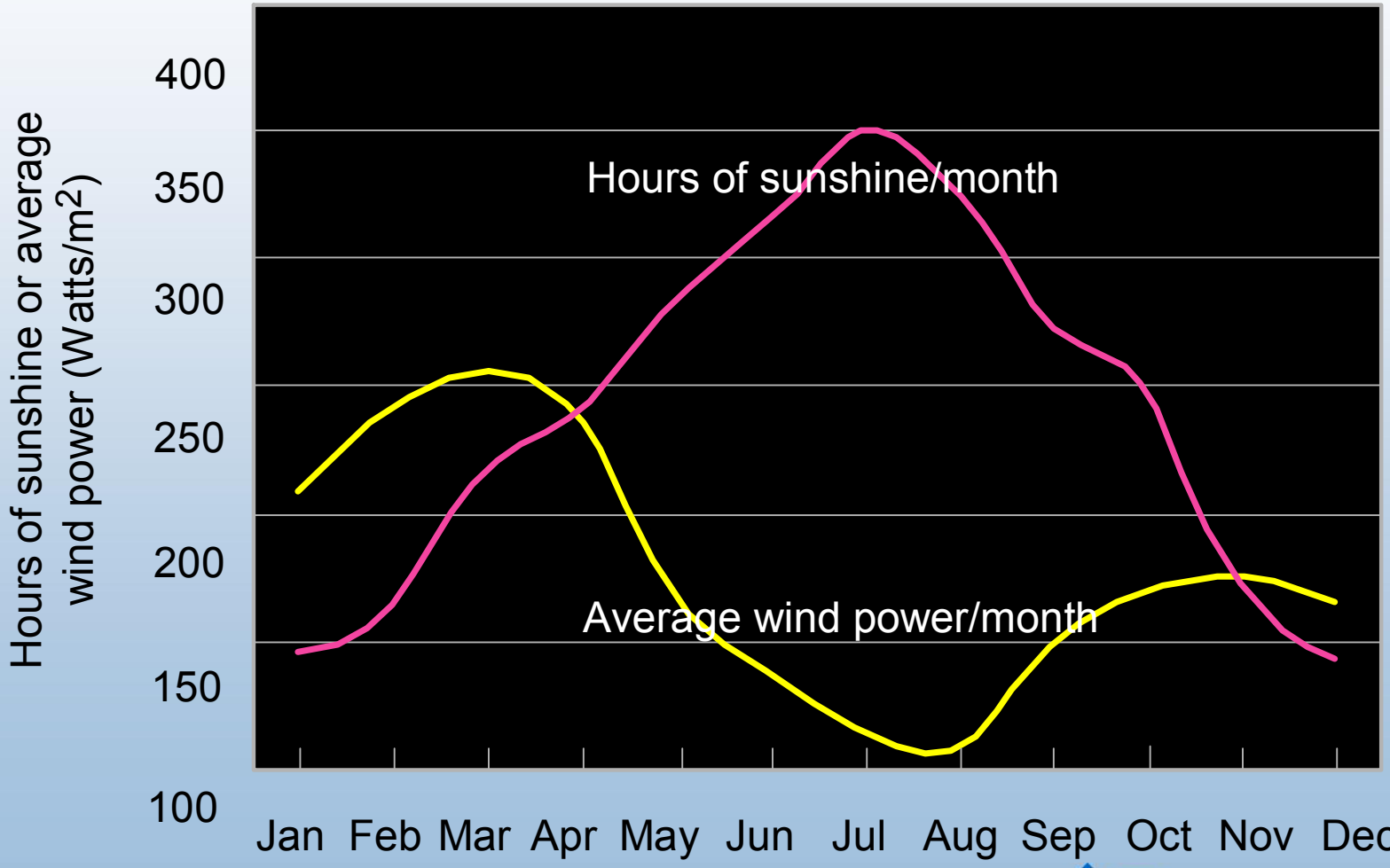
Wind Energy
US Winter Wind Resource



Hybrid Wind-Solar Systems

Solar and Wind Resources are Complimentary

Data from SE Iowa



A Future Vision for Wind Energy Markets

Today 2006

Bulk Power Generator
5-8¢ at 15mph

- Land Based
- Bulk Electricity
- Wind Farms

Potential 20% of Electricity Market

Tomorrow

Land Based Electricity Path

Land Based LWST Large-Scale 2–5 MW

Transmission Barriers

LWST Turbines:
- 3.6¢/kWh at 13mph
- Electricity Market

2012

Offshore Electricity Path

Offshore Turbines 5 MW and Larger

Cost & Regulatory Barriers

Offshore LWST Turbine:
- 5 cents/kWh
- Shallow/***Deep*** *water*
- Electricity Market
- Higher wind Sites

2012 and Beyond

Advanced Applications Path

Land or Sea Based:
- **Hydrogen**
- **Clean Water**

Cost & Infrastructure Barriers

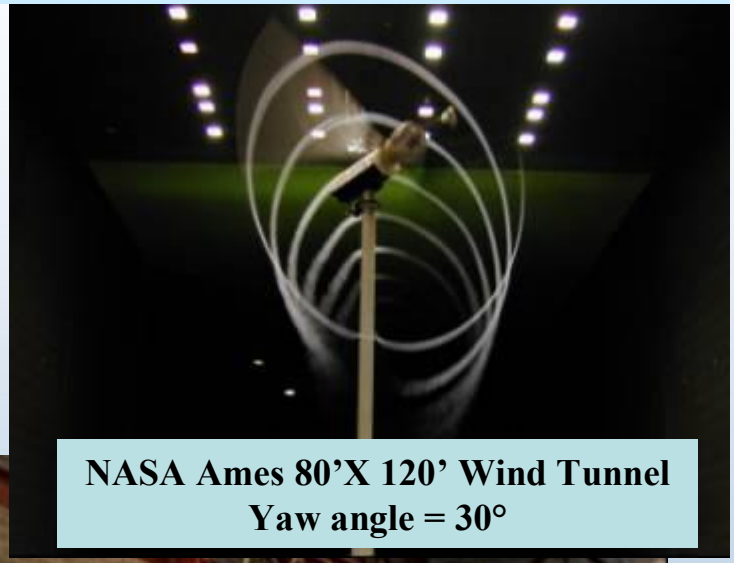
Custom Turbines:
- Electricity
- H2 production
- Desalinate water
- Storage
- Multi-Market

2030 and Beyond

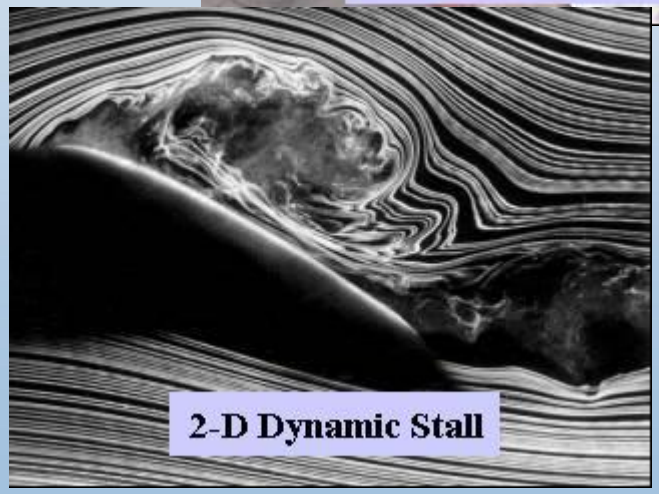
NREL's National Wind Technology Center Research and Development

Basic & Applied Research & World-Class Testing Facilities

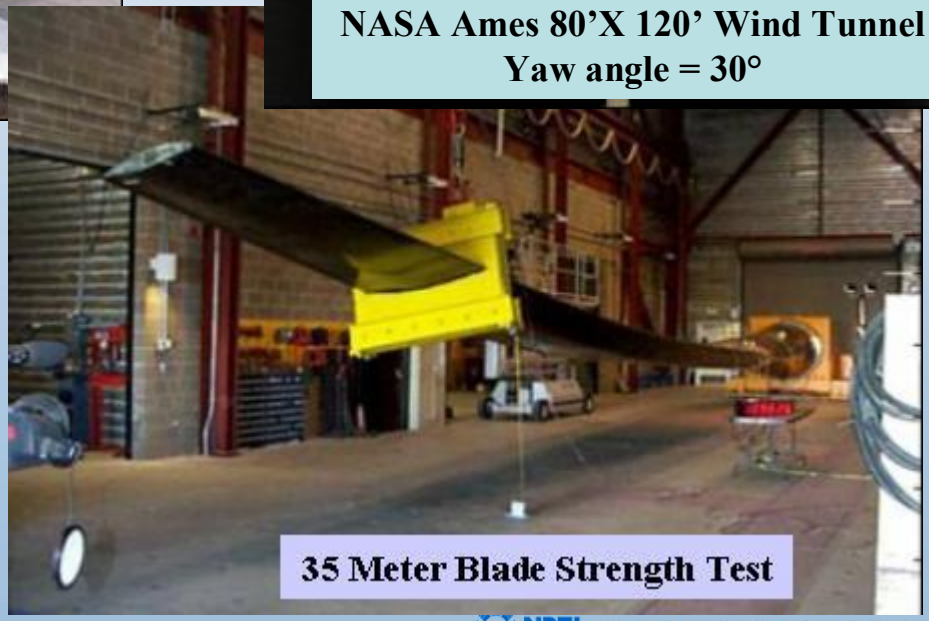
GE Wind Energy
1.5 MW Drive Train



NASA Ames 80'X 120' Wind Tunnel
Yaw angle = 30°



2-D Dynamic Stall



35 Meter Blade Strength Test

Questions?

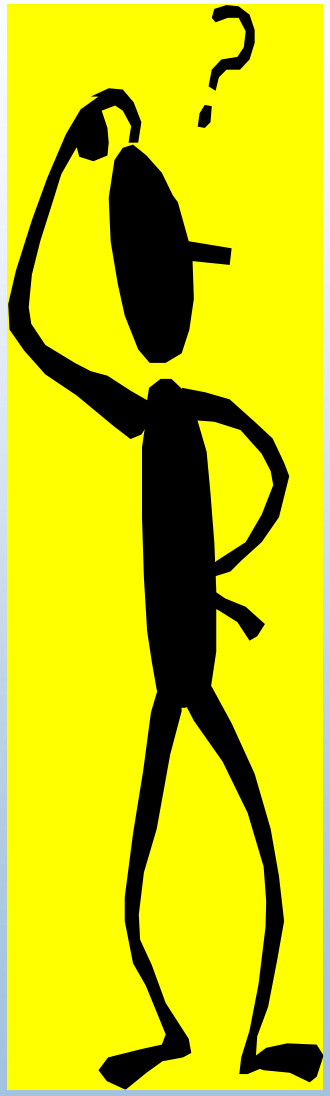
For more info:

http://www.nrel.gov/wind/

http://www.awea.org/

http://rredc.nrel.gov/wind/pubs/atlas/

http://www.windpower.org/en/core.htm



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